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Sockeye Salmon (*Oncorhynchus nerka*):
Summary of Fisheries Production
(1976-1989)

by
R. S. Chlupach and G. B. Kyle

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October 1990

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ABSTRACT

Over 103 million sockeye salmon (*Oncorhynchus nerka*) fingerlings were released into Big Lake during 1976-1989 and contributed an average of 70% to the annual smolt migration. Although increased numbers of hatchery fingerlings released into Big Lake resulted in significantly (Spearman's Rho = .90, $p<.05$; $r^2 = .90$, $p = .02$) greater number of hatchery smolts; the average survival of hatchery fingerlings was exceptionally low (5%). In contrast, the number of wild smolts produced was not significantly related to the magnitude of the parent escapements, and the average smolt survival for wild fingerlings was only 1.5%. The return of adult sockeye salmon to Big Lake was significantly (Mann-Whitney U-test; $p<.05$) greater after enhancement. The estimated hatchery contribution to the return of adults to the weir averaged 61%, and the percentage of hatchery smolts that returned as adults to the weir averaged 19.8%. Finally, it is apparent that factors other than the number of hatchery sockeye salmon fingerlings released, or the magnitude of natural recruitment in Big Lake affect sockeye salmon production in Big Lake, and further study is needed. In the future, a management plan should be developed to define salmon production goals relative to economic and social interests, water quality assurance, fish habitat, and the future of fisheries enhancement in Big Lake.

INTRODUCTION

Historically, Big Lake has been one of the major sockeye salmon (*Oncorhynchus nerka*) systems in Cook Inlet. Sockeye salmon escapements from 1940 through 1960 ranged from 40,800 to 131,200 fish. The mean sockeye salmon escapement during 1970-1975 just prior to initiation of enhancement (1976) was 18,799. As a result of increasing concern over the declining returns of adult sockeye salmon, basic studies of sockeye nursery lakes within the Cook Inlet watershed were initiated in 1972 by authority of the Alaska Senate Concurrent Resolution No. 27. This resolution requested that the Alaska Department of Fish and Game (ADF&G) establish a "comprehensive salmon rehabilitation and restoration program in the Cook Inlet watershed" to expedite the rebuilding of salmon stocks. Consequently, the Commercial Fisheries Division of ADF&G engaged in studies of several lakes throughout the Cook Inlet region in 1972 and 1973 (Bill et al. 1972; Barton and Barrett 1973), and found that Big Lake had the rearing potential to support additional sockeye salmon.

Since 1975, sockeye salmon eggs have been taken from Big Lake and incubated and reared to fingerlings at the Big Lake Hatchery (Figure 1). In 1976, basic fisheries data collection (smolt and adult enumeration and sampling) was initiated. Hatchery-produced sockeye salmon fingerlings were first released into Big Lake in 1977. Prior to and after 1983 and 1984, limited limnological data were collected; however, a detailed limnological assessment of Big Lake was conducted by limnologists of the United States Geological Survey in 1983 and 1984 (Woods 1986a).

The objective of this report is to summarize wild and hatchery production of sockeye salmon smolts and adults in Big Lake. In addition, this report discusses results of the hatchery fingerling plants and makes recommendations regarding further study of sockeye salmon production in Big Lake. In the future, fisheries information will be integrated with limnological data to assist in developing a salmon management plan for Big Lake.

Description of Study Area

Big Lake (61°31'45"N, 149°59'00"W) is located in the Matanuska-Susitna Valley of Southcentral Alaska ~24 km west of Wasilla, Alaska (Figure 1). The main tributary of Big Lake is Meadow Creek which drains over 30 lakes and ponds. Other tributaries enter the lake from watersheds through Mirror and Flat Lakes. The lake outlet, Fish Creek, flows ~23 km into Knik Arm of northern Cook Inlet. Big Lake is comprised of five major basins; the two deeper (~20 m) basins lie in the western end of the lake while the three shallower (~12 m) basins lie in the eastern end of the lake (Figure 2). The main western basin is catergorized as oligotrophic and the main eastern basin is mesotrophic (Woods 1986b). The lake has a mean euphotic zone depth of 11.5 m and an euphotic volume of 108.9 x 10^6 m^3. The length of the lake is about 6.4 km, and ranges in width from 0.8-3.2 km; the surface area is 10.1 x 10^6 m^2, the mean depth is 9.2 m, and the volume is 111.9 x 10^6 m^3.

All five species of Pacific salmon inhabit the Big Lake watershed; however, sockeye and coho salmon (*Oncorhynchus kisutch*) dominate and are the only two salmon species that have been observed entering the lake. Other fish species include; rainbow trout (*Oncorhynchus mykiss*), Arctic char (*Salvelinus alpinus*), round whitefish (*Prosopium cylindraceum*), burbot (*Lota lota*), longnose sucker (*Catostomus catostomus*), slimy sculpin (*Cottus cognatus*), prickly sculpin (*Cottus asper*), threespine stickleback (*Gasterosteus aculeatus*), ninespine stickleback (*Pungitius pungitius*), and Arctic lamprey (*Lampetra japonica*).

Finally, a large number of residences and public access points have contributed to the growth and popularity of recreational activities at Big Lake. Currently, there are 934 lake-front lots that support in excess of 500 lake-front cabins or residences, two state waysides, a private commercial campground, two boat marinas, and at least seven lounge and restaurant facilities including three lodges.

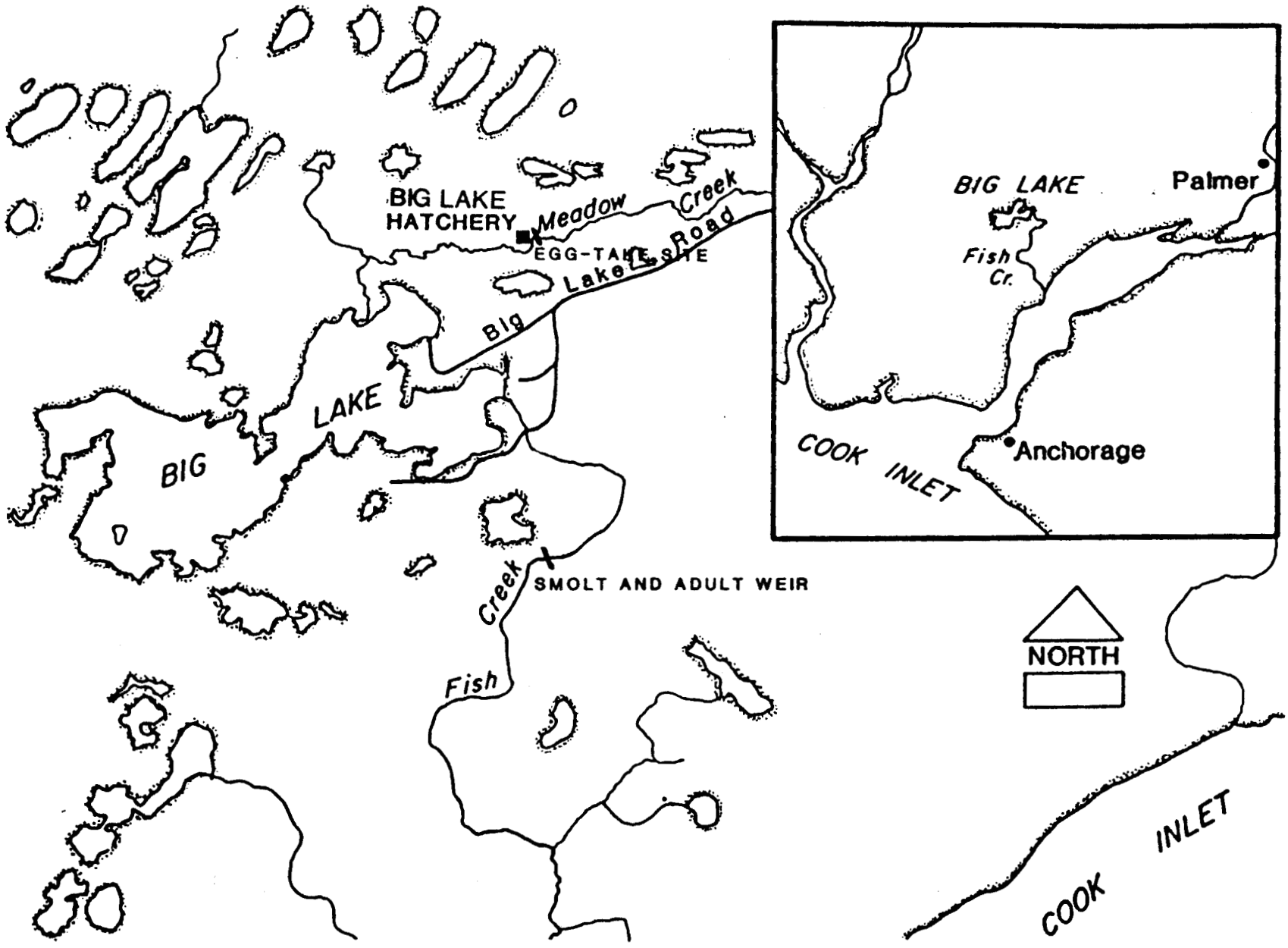

Figure 1. Area map of Big Lake in Southcentral Alaska showing locations of Big Lake Hatchery, the smolt and adult weirs, and the egg-take site.

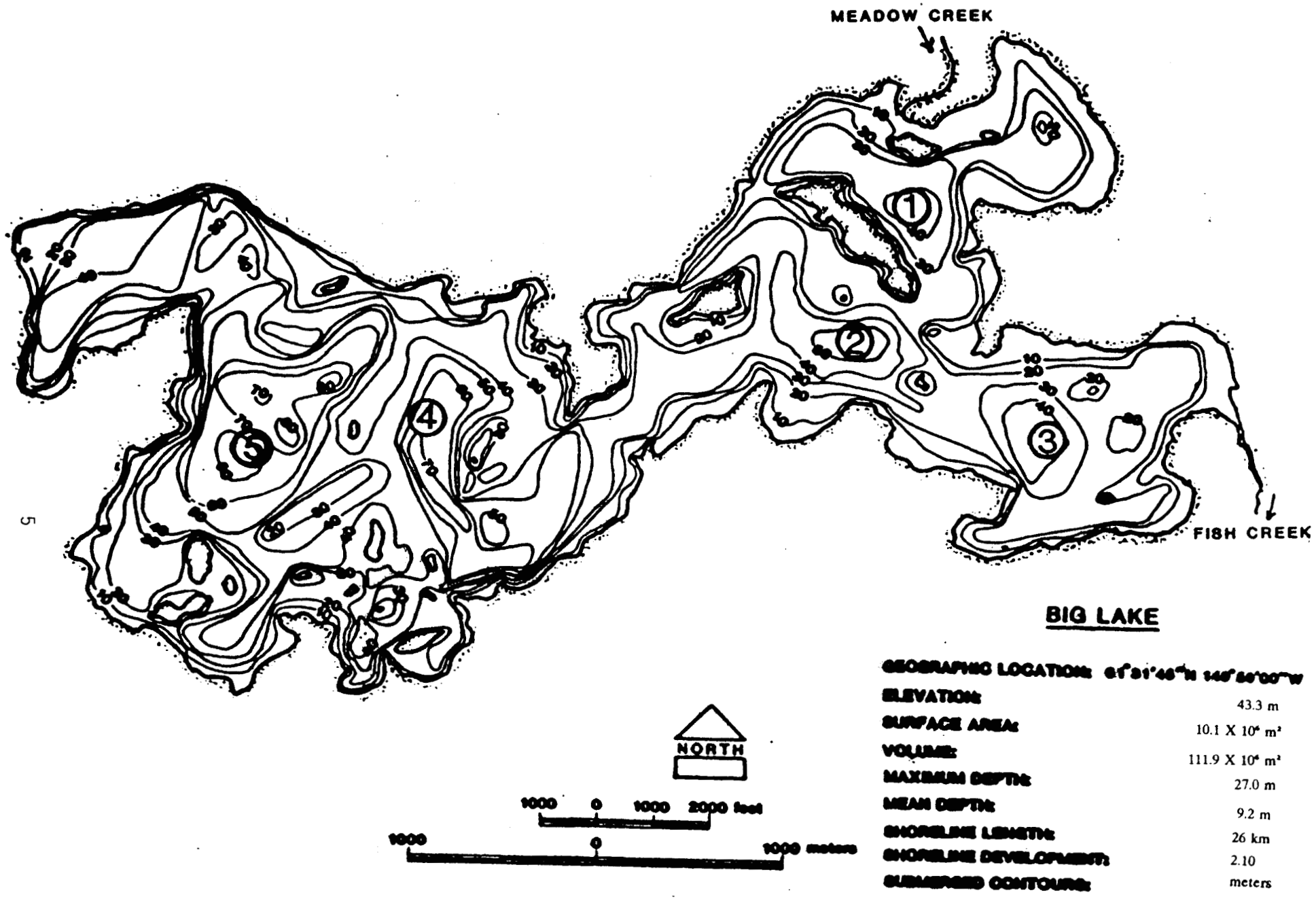

Figure 2. Morphometric map of Big Lake showing locations of the five major basins.

METHODS

Egg Takes and Fingerling Releases

From 1975 through 1980, egg-take procedures consisted of placing eggs and milt in a bucket from more than two adult fish. However, as a result of major outbreaks of infectious hematopoietic necrosis virus (IHNV) in 1979 and 1980, in 1981 egg-take procedures were modified so that eggs from individual fish were kept separate. In addition, strict disinfection techniques were followed before and after fertilization, as outlined in the ADF&G Fish Culture Manual (ADF&G 1983).

The procedures used in marking sockeye salmon fingerlings at Big Lake Hatchery followed the mark-tag manual for salmon (Moberly et al. 1977). In 1977 and 1978, fingerlings were marked with a ventral fin clip; however, as a result of the IHNV outbreaks in 1979 and 1980, no marked sockeye salmon fingerlings were released from 1980 through 1984. Marking resumed in 1985 using a coded-wire-tag (CWT) embedded in the snout of fingerlings, in conjunction with an adipose fin clip. The percentage of fingerlings marked each year ranged from 0.2-1.9% of the total number released. For the most part, sockeye salmon fingerlings were released at the hatchery to develop a broodstock. In recent years, up to 1 million fingerlings have been transported by truck and released alongshore at known spawning locations.

Enumeration and Sampling of Sockeye Salmon Smolts

A smolt fyke net (Chlupach 1986) was used to enumerate smolts in Fish Creek (Figure 1) and was operated from the first week in May until the end of June. The number of sockeye salmon smolts migrating from Big Lake were estimated using two techniques. Individual total counts of smolts were conducted when less than 3,000 fish per hour were migrating. When the migration passage rate exceeded 3,000 fish/hr, a timed subsampling method was employed (Litchfield and Flagg 1988). The same counting techniques were followed each year, with only a minor variation in the

percentage of time subsampled (ranged from 10-30%), due to differences in the migrational intensity of smolts.

Each day, when available, 30 sockeye salmon smolts were anesthetized in a tricaine methanesulfonate (MS-222) solution, measured to the nearest millimeter (snout-to-fork of tail), and weighed to the nearest 0.1 g. A scale smear was taken from each specimen, placed on a glass slide, and ages were determined using a microfiche projector. Lengths, weights, and age-class compositions were weighted over the migration period by seven-day intervals (Cochran 1977).

Enumeration and Sampling of Sockeye Salmon Adults

A V-shaped weir in Fish Creek (Figure 1) was used to enumerate migrating adult sockeye salmon beginning the first week in July through early to mid-September. Statewide stock biology techniques (ADF&G 1984) were used in sampling adults for age, weight, and length.

Contribution of Hatchery-Produced Sockeye Salmon

The proportional contribution of hatchery-produced smolts in the outmigration and hatchery-produced adults in the return to the weir were computed using the following formula (Chlupach 1988):

$$\hat{P}_s = \frac{m_c}{\theta \times n_c}$$

and

$$V(\hat{P}_s) = \frac{m_c}{n_c \times (n_c - 1) \times \theta^2} \times 1-(m_c \div n_c)$$

Where:

$\hat{P}_s$ = the proportional contribution of the enhanced stock,

m_c = the number of marks from the enhanced stock observed in the fishery,

θ = the proportion of the enhanced stock marked at the time of release,

n_c = the number of examined fish, and

$V(\hat{P})_s$ = the variance for the proportional contribution of the enhanced stock.

RESULTS

Egg Takes and Fingerling Releases

An average fecundity of 2,897 eggs per female from over 60,000 adult female sockeye salmon has resulted in the incubation of over 175 million Big Lake sockeye salmon eggs at the Big Lake Hatchery from 1976 through 1989 (Table 1). Excluding brood years 1978 and 1979, when IHNV affected production, the mean egg-to-fingerling survival was 71.9%. Despite major losses of fry in 1978 and 1979 due to IHNV, Big Lake Hatchery has released over 103 million sockeye salmon fingerlings into Big Lake. The average number of fingerlings released into Big Lake each year was 8,629,015; however, since 1984 an average of 13,410,808 fingerlings have been released.

Production of Wild and Hatchery Sockeye Salmon Smolts

The number of sockeye salmon smolts migrating from Big Lake ranged from 53,278-1,383,220 and averaged 517,042 during 1976-1989 (Table 2). The estimated percentage contribution of hatchery-produced sockeye salmon smolts to the total

Table 1. Summary of sockeye salmon egg takes and fingerling releases at Big Lake, 1976-1989.

Brood year	No. eggs taken	No. females used for egg take	Fecundity	No. fingerlings released	Egg to fingerling survival (%)	Type of mark*	No. marked	Percent marked
1976	10,034,013	3,488	2,877	7,686,382	76.6	Ad+V	72,673	0.9
1977	8,748,867	2,967	2,949	5,739,010	65.6	Ad+V	66,153	1.2
1978	9,832,726 **	3,012	3,265	0	0.0			
1979	5,053,808 ***	1,518	3,329	806,047	15.9	****	0	0.0
1980	4,699,733	1,911	2,459	3,967,941	84.4	****	0	0.0
1981	5,662,004	2,179	2,598	4,263,356	75.3	****	0	0.0
1982	8,624,662	3,985	2,164	6,601,409	76.5	****	0	0.0
1983	16,100,000	5,334	3,018	7,430,000	46.1	****	0	0.0
1984	16,210,000	5,656	2,866	12,430,000	76.7	HLCWT	18,835	0.2
1985	21,577,000	6,931	3,113	15,059,184	69.8	HLCWT	18,120	0.1
1986	16,839,000	5,684	2,963	11,867,000	70.5	HLCWT	19,613	0.2
1987	20,273,000	6,907	2,935	14,492,000	71.5	HLCWT	20,085	0.1
1988	16,892,000	5,764	2,931	13,205,848	78.2	HLCWT	24,848	0.2
1989	14,835,000	5,196	2,855					
Total	175,381,813	60,532		103,548,177			240,327	
Mean	12,527,272	4,324	2,897	8,629,015	71.9			0.2

* Adipose clip and ventral clip (Ad+V) and half length coded wire tag (HLCWT).

** All fish were destroyed due to infectious hematopoietic necrosis virus (IHNV).

*** The majority were lost to IHNV.

**** No fish were marked during release years 1980-1984 per pathology recommendations as a result of IHNV.

Table 2. Summary of smolt migrations, hatchery contributions, ages, and sizes for Big Lake sockeye salmon smolts, 1976-1989.

Smolt year	Number of smolts			Hatchery contribution (%)	Age class composition (%)		Mean length mm (S.D.)		Mean weight g (S.D.)		No. sampled
	Wild	Hatchery	Total		age-1	age-2	age-1	age-2	age-1	age-2	
1976	53,278	0	53,278	0	64	36	135 (7)	185 (11)	26.5 (3.7)	67.3 (8.7)	277
1977	140,504	57,389	197,893	29	99	1	134 (7)	150 (17)	26.0 (2.9)	34.1 (15.3)	1,062
1978	390,352	282,668	673,020	42	95	5	118 (7)	161 (14)	15.7 (3.8)	40.3 (10.2)	1,350
1979	89,171	145,488	234,659	62	92	8	123 (6)	159 (21)	17.1 (3.1)	39.8 (19.1)	870
1980	40,660	0	40,660	0	94	6	129 (6)	166 (11)	21.6 (2.9)	42.4 (10.6)	507
1981	ND*	ND*	429,790	ND*	93	7	123 (6)	118 (5)	18.8 (3.0)	16.2 (2.4)	656
1982	ND*	ND*	660,150	ND*	87	13	126 (6)	143 (5)	19.3 (2.7)	29.9 (4.3)	474
1983	ND*	ND*	291,020	ND*	95	5	137 (5)	172 (13)	26.5 (4.3)	51.5 (14.0)	441
1984	ND*	ND*	124,167	ND*	92	8	135 (5)	175 (12)	27.5 (4.1)	55.3 (9.1)	542
1985	ND*	ND*	568,740	ND*	84	16	134 (6)	178 (11)	30.5 (3.9)	56.5 (10.1)	531
1986	156,637	764,764	921,401	83	96	4	133 (5)	180 (12)	23.9 (2.5)	61.9 (11.5)	445
1987	248,981	1,134,239	1,383,220	82	91	9	121 (5)	162 (15)	16.7 (2.3)	40.0 (9.1)	480
1988	23,690	568,567	592,257	96	98	2	127 (6)	162 (11)	19.9 (3.0)	41.4 (9.9)	585
1989	53,417	1,014,922	1,068,339	95	88	12	125 (5)	163 (8)	18.7 (2.5)	39.2 (8.9)	400
Mean	132,885**	566,966**	517,042	70	91	9	130	163	23.5	44.9	

* No fish were marked during release years 1980-1984 per pathology recommendations as a result of IHNV. Consequently, the number of wild and hatchery smolts could not be apportioned during smolt years 1981-1985.

** Average of years with known apportionments of wild and hatchery smolt production.

smolt migration averaged 70%, and ranged from a low of 29% in 1977 to a high of 96% in 1988. In addition, the annual production of wild and hatchery-produced smolts averaged 132,885 and 566,966 respectively, during years with known apportionments of wild and hatchery fish.

The age composition of migrating smolts averaged 91% age-1 (ranged from 64-99%) and 9% age-2 (ranged from 1-36%) during 1976-1989 (Table 2). The size of age-1 smolts ranged from 118-137 mm in length and 15.7-38.4 g in weight, and averaged 130 mm and 23.5 g; for age-2 smolts the size ranged from 118-185 mm and 16.2-67.3 g, and averaged 163 mm and 44.9 g. In addition, there was no significant (Spearman's Rho = -.56, $p > .05$; $r^2 = .21$, $p = .08$) relationship between the total number of smolts and the size of age-1 smolts (Figure 3).

The fingerling-to-smolt survival for hatchery fingerlings during years in which hatchery smolt production could be estimated (when fingerlings were marked) averaged 4.9% (Table 3). The estimated survival of wild fingerlings to the smolt stage, based on a mean fecundity of 2,897 and a 10% egg-to-fingerling survival, averaged 1.5%. The estimated fingerling-to-smolt survival for wild fish decreased from approximately 4.0% to 0.0% during 1976-1989, while hatchery-produced fish increased from 3.6% to greater than 7.0%. In addition, a significant (Spearman's Rho = .90, $p<.05$; $r^2 = .90$, $p = .02$) positive correlation was found between the respective number of hatchery fingerlings released and the number of hatchery smolts produced (Figure 4).

Returns of Wild and Hatchery Sockeye Salmon Adults to the Weir

During 1976-1989 a mean of 62,202 sockeye salmon escaped into Big Lake (Table 4). Adult sockeye salmon escapements ranged from a high of 192,352 in 1984 to a low of 3,555 in 1978. Hatchery-produced fish returned ten out of the 14 years during 1976-1989; however, only during five years when marked adult sockeye salmon were present (pathology guidelines prevented the marking of fingerlings in the other five

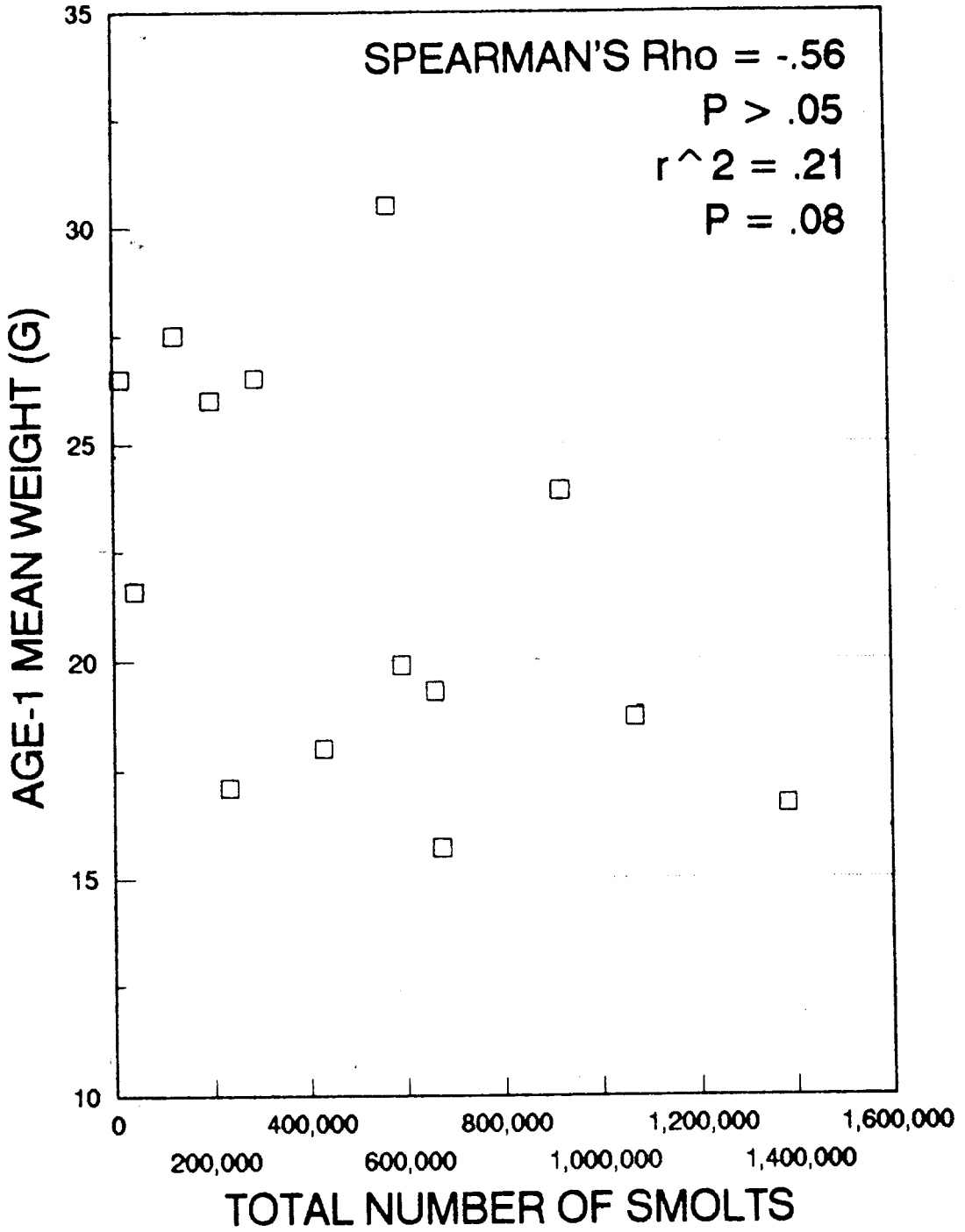

Figure 3. Relationship between the total number of smolts produced and mean weight of age-1 smolts for Big Lake sockeye salmon, 1976-1989.

Table 3. Numbers of wild and hatchery sockeye salmon produced from parent-year escapements (less fish used for egg takes) and hatchery fingerling releases in Big Lake during 1976-1989.

Parent year	Parent year escapement	Release year	No. of hatchery fingerlings released	Smolt production (number of fish) Smolt years	Wild Age-1	Wild Age-2	Hatchery Age-1	Hatchery Age-2	Hatchery fingerling to smolt survival (%)	Est. wild fingerling to smolt survival (%)*
1976	14,032	1977	7,686,382	1978	370,834		268,535		3.6	3.8
				1979		7,134		11,639		
1977	5,183	1978	5,739,010	1979	82,037		133,849		2.3	4.0
				1980		2,440		0		
1978	3,555	1979	0	1980	38,220		0			
				1981		ND		ND		
1979	68,739	1980	806,047	1981	ND	ND	ND	ND		
				1982	ND	ND	ND	ND		
1980	62,828	1981	3,967,941	1982	ND	ND	ND	ND		
				1983	ND	ND	ND	ND		
1981	50,479	1982	4,263,356	1983	ND	ND	ND	ND		
				1984	ND	ND	ND	ND		
1982	28,164	1983	6,601,409	1984	ND	ND	ND	ND		
				1985	ND	ND	ND	ND		
1983	118,797	1984	7,430,000	1985	ND	ND	ND	ND		
				1986	ND	ND	ND	ND		
1984	192,352	1985	12,430,000	1986	76,439		401,303		4.0	0.6
				1987		90,998		102,081		
1985	68,577	1986	15,059,184	1987	226,571		1,032,157		6.9	0.3
				1988		22,408		11,371		
1986	29,800	1987	11,867,000	1988	23,216		557,195		5.7	0.1
				1989		744		121,790		
1987	89,493	1988	14,492,000	1989	47,006		1,014,922		7.0 **	0.0
				1990						
								Mean	4.9	1.5

* Assumed fecundity of 2,897 and 10% egg-to-fingerling survival.

** Includes survival of only age-1 smolts.

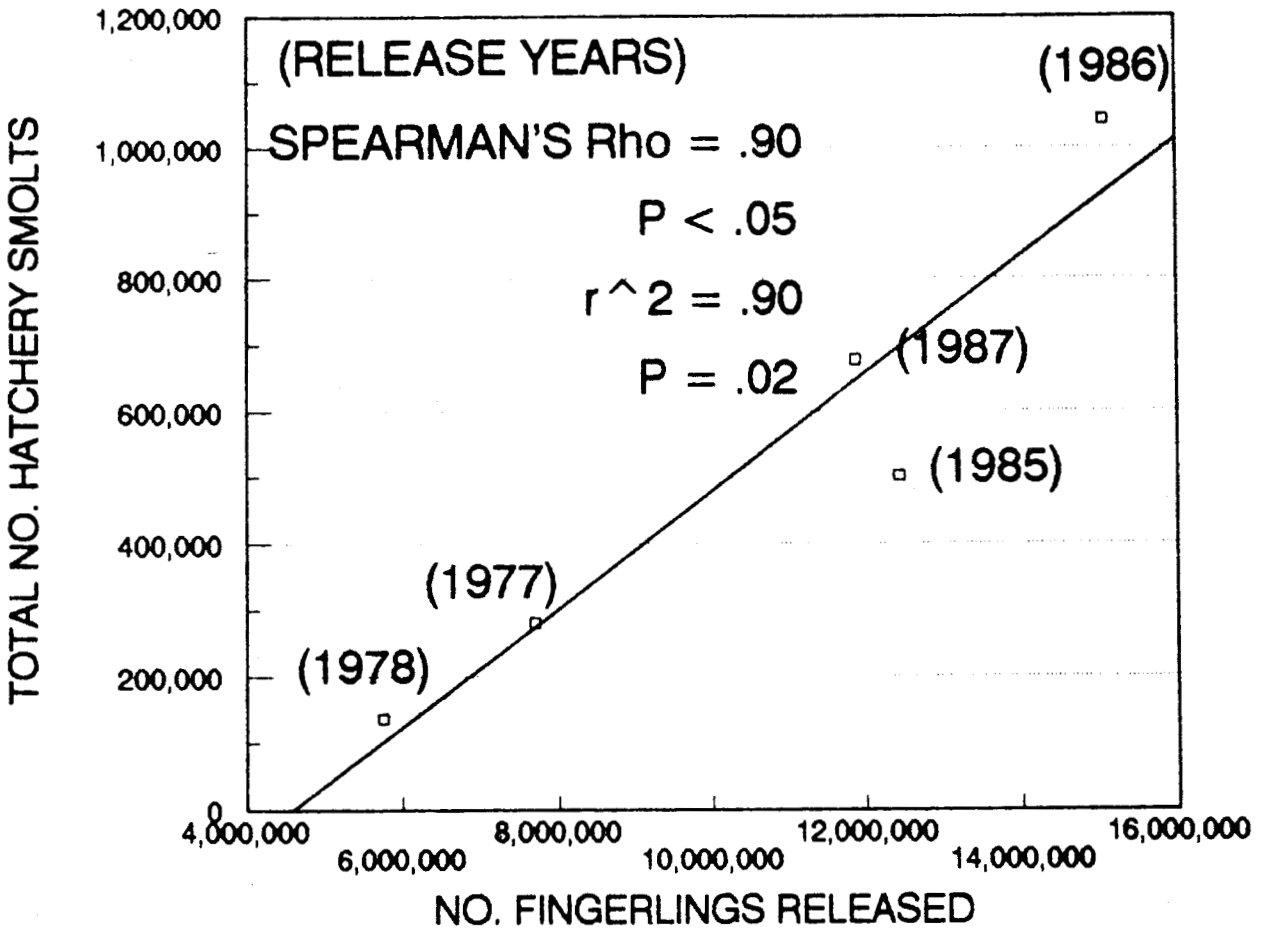

Figure 4. Relationship between the number of hatchery fingerlings released and total number of hatchery smolts produced for Big Lake sockeye salmon.

Table 4. Summary of Big Lake adult sockeye salmon weir returns, hatchery contributions, ages, and sizes, 1976-1989.

Return year	Number of adults			Hatchery contribution	Age class composition (%)*			Mean length (mm)			Mean weight (kg)		
	Wild	Hatchery	Total	(%)	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2
1976	14,032	0	14,032	0	69	21	6	ND	ND	ND	ND	ND	ND
1977	5,183	0	5,183	0	34	51	3	ND	ND	ND	ND	ND	ND
1978	3,555	0	3,555	0	40	5	1	503	549	539	1.8	2.2	1.9
1979	51,554	17,185	68,739	25	90	2	1	511	551	546	1.7	1.9	2.1
1980	40,210	22,618	62,828	36	73	12	4	502	523	543	1.6	2.0	2.1
1981	13,629	36,850	50,479	73	61	33	5	514	548	541	2.0	2.4	2.2
1982	28,164	0	28,164	0	24	65	2	532	557	550	2.4	2.6	2.4
1983	ND	ND	118,797	ND	86	1	2	500	508	513	1.8	1.8	1.8
1984	ND	ND	192,352	ND	86	6	5	481	515	551	1.6	1.9	2.3
1985	ND	ND	68,577	ND	55	33	4	499	551	531	1.7	2.3	1.9
1986	ND	ND	29,800	ND	79	15	2	491	533	502	1.7	1.8	1.7
1987	ND	ND	89,493	ND	87	5	4	508	558	494	1.8	2.3	1.7
1988	7,160	64,443	71,603	90	92	0	3	471	-	428	1.5	-	1.0
1989	12,100	55,121	67,221	82	62	20	5	494	544	489	1.8	2.4	1.7
Mean	19,510	39,243 **	62,202	61	78	12	4	501	495	519	1.8	2.0	1.9

* Only the three major age groups per return year are presented.

** Mean for years when hatchery fish returned.

years due to the outbreak of IHNV), could the contribution of hatchery fish be estimated. Returns of hatchery-produced fish averaged 39,243 for the five years of evaluated hatchery returns, which represents an average contribution of 61% to the total escapement during those years (Table 4). Wild sockeye salmon returns to the weir during 1976-1989 averaged 19,510. There was no significant (Spearman's Rho = .10, $p>.05$; $r^2 = .0007$, $p = .97$) relationship between sockeye salmon escapements into Big Lake and the number of wild smolts produced (Figure 5). In addition, conditional smoothing of data in this relationship using a locally weighted robust regression (LOWESS) procedure yielded a non-functional relationship. Finally, the percentage of smolts that returned as adult sockeye salmon to Big Lake ranged from 6.5-35.4%, and averaged 19.8% during 1976-1989 (Table 5).

Except for 1978, in which 55% of the adult sockeye salmon returning to Big Lake were age-1.1 fish, the age class composition comprised mainly of three age groups; age-1.2 (78%), age-1.3 (12%), and age-2.2 (4%) (Table 4). The mean lengths and weights for age-1.2 fish were 501 mm and 1.8 kg, for age-1.3 fish were 540 mm and 2.1 kg, and for age-2.2 fish were 519 mm and 1.9 kg.

The sockeye salmon escapement into Big Lake averaged 81,989 for the period when hatchery fish returned (1979-1989), and was significantly (Mann Whitney U-test; $p<.05$) greater than during the period before enhancement (1936-1978), when the average escapement was 54,895 sockeye salmon (Table 6). Although there was a positive and significant (Spearman's Rho = .94, $p<.05$; $r^2 = .91$, $p = .003$) relationship between the respective number of hatchery-produced smolts and number of returning hatchery adults to the weir (Figure 6A); there was no significant relationship between the respective number of wild smolts produced and the number of returning wild adults to the weir (Figure 6B).

Finally, a comparison of escapements into Big Lake during 1979-1989 when hatchery fish returned and into the Susitna River system, a major upper Cook Inlet sockeye salmon producer adjacent to Big Lake, reveals dissimilar trends in escapement levels

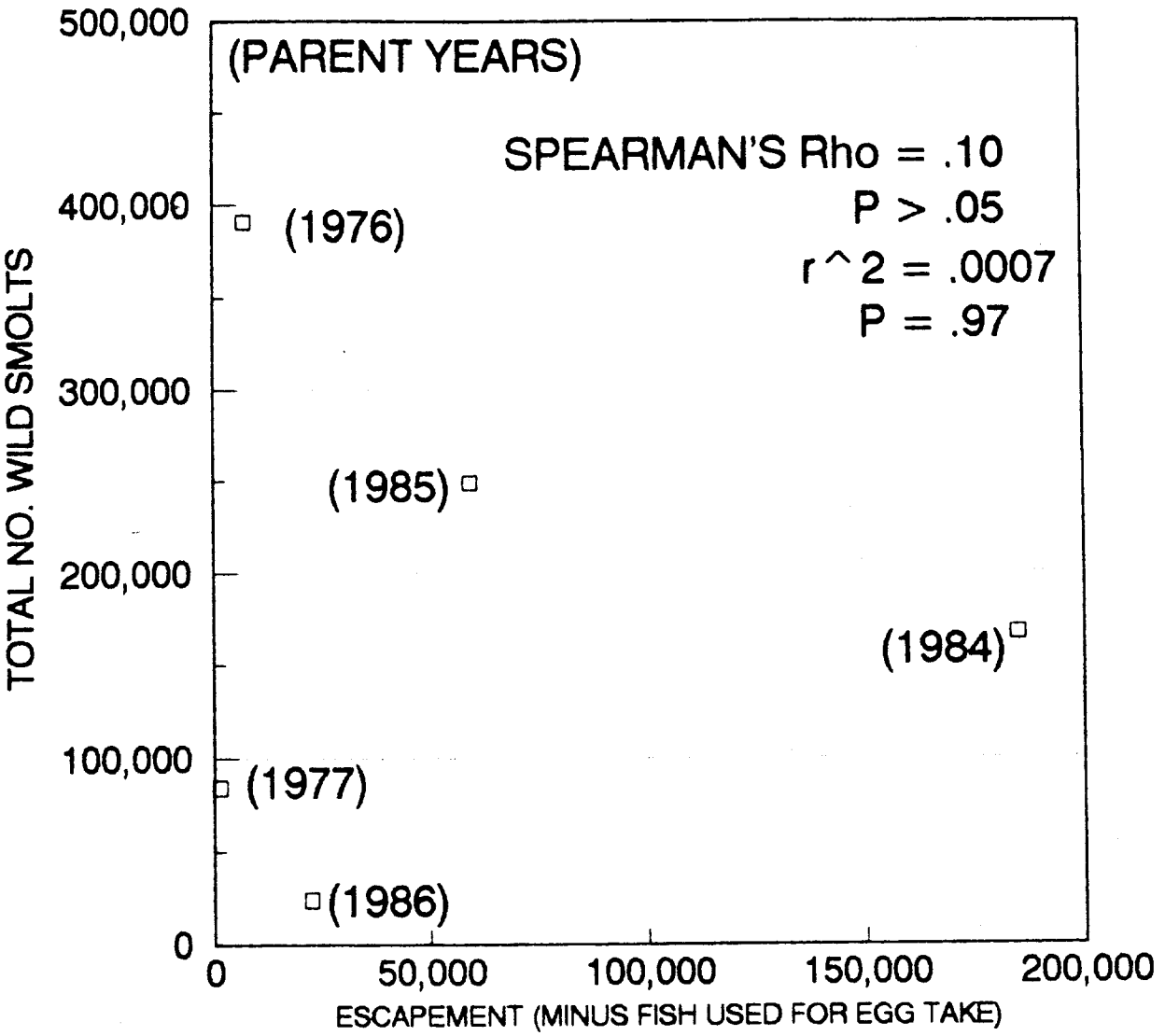

Figure 5. Relationship between sockeye salmon escapement minus the fish used for egg takes and the total number of wild smolts produced in Big Lake.

Table 5. Adult wild and hatchery sockeye salmon returns by age group to the Big Lake weir from smolt years 1976-1989.

Smolt year	Number of smolts					Number of adults returning to weir							Smolt to adult return to weir (%)
	Wild		Hatchery			Wild			Hatchery				
	Age-1	Age-2	Age-1	Age-2	Total	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2	Total	
1976	37,740	15,538	0	0	53,278	1,422	1,375	688	0	0	0	3,485	6.5
1977	139,099	1,405	56,815	574	197,893	46,399	5,654	516	15,466	1,884	172	70,091	35.4
1978	370,834	19,518	268,535	14,133	673,020	29,353	4,825	1,608	16,511	12,160	905	65,362	9.7
1979	82,037	7,134	133,849	11,639	234,659	8,314	4,498	681	22,478	8,787	1,842	46,600	19.9
1980	38,220	2,440	0	0	40,660	6,151	1,188	513	0	0	0	7,852	19.3
1981	ND	ND	ND	ND	429,790	ND	ND	ND	ND	ND	ND	118,797	27.6
1982	ND	ND	ND	ND	660,150	ND	ND	ND	ND	ND	ND	192,352	29.1
1983	ND	ND	ND	ND	291,020	ND	ND	ND	ND	ND	ND	68,577	23.6
1984	ND	ND	ND	ND	124,167	ND	ND	ND	ND	ND	ND	29,800	24.0
1985	ND	ND	ND	ND	568,740	ND	ND	ND	ND	ND	ND	81,438	14.3
1986	150,373	6,264	734,174	30,590	921,401	6,587	2,420	215	59,288	11,024	1,933	81,467	8.8
1987	226,571	22,410	1,032,157	102,082	1,383,220	7,502	NA	605	34,175	NA	2,756	45,038	3.3*
1988	23,216	474	557,195	11,372	592,257	NA	NA	NA	NA	NA	NA	NA	NA
1989	47,007	6,410	893,131	121,791	1,068,339	NA	NA	NA	NA	NA	NA	NA	NA
Mean	123,900	9,066	408,428	32,465	517,042	15,104	3,327	689	29,584	8,464	1,268	67,572	19.8 **

* Does not include return of three-ocean age fish.

** Excludes incomplete adult return from smolt year 1987.

Table 6. Summary of sockeye salmon escapements into Big Lake, 1936-1989.

Return year	Weir escapement count
1936	203,039
1937	50,617
1938	182,463
1939	116,588
1940	306,982
1941	55,077
1942	NA
1943	NA
1944	NA
1945	NA
1946	57,000
1947	150,000
1948	150,000
1949	68,240
1950	29,659
1951	34,704
1952	92,724
1953	54,343
1954	20,904
1955	32,724
1956	32,663
1957	15,630
1958	17,573
1959	77,416 *
1960	80,000 *
1961	40,000 *
1962	60,000 *
1963	119,024 *
1964	65,000 *
1965	16,544 *
1966	41,312 *
1967	22,624 *
1968	19,616 *
1969	12,456
1970	25,000
1971	32,000
1972	6,981
1973	2,705
1974	16,225
1975	29,882
1976	14,032
1977	5,183
1978	3,555
Mean 1936-1978	54,895

-continued-

Table 6 continued. Summary of sockeye salmon escapements into Big Lake, 1936-1989.

Return year	Weir escapement count
1979	68,739 **
1980	62,828 **
1981	50,479 **
1982	28,164
1983	118,797 **
1984	192,352 **
1985	68,577 **
1986	29,800 **
1987	89,493 **
1988	71,603 **
1989	67,221 **
Mean 1979-1989	81,989 ***

* A counting screen was used.

** Years when hatchery fish contributed to the escapement.

*** Excludes 1982 (no hatchery fish returned due to no release of fingerlings in 1979).

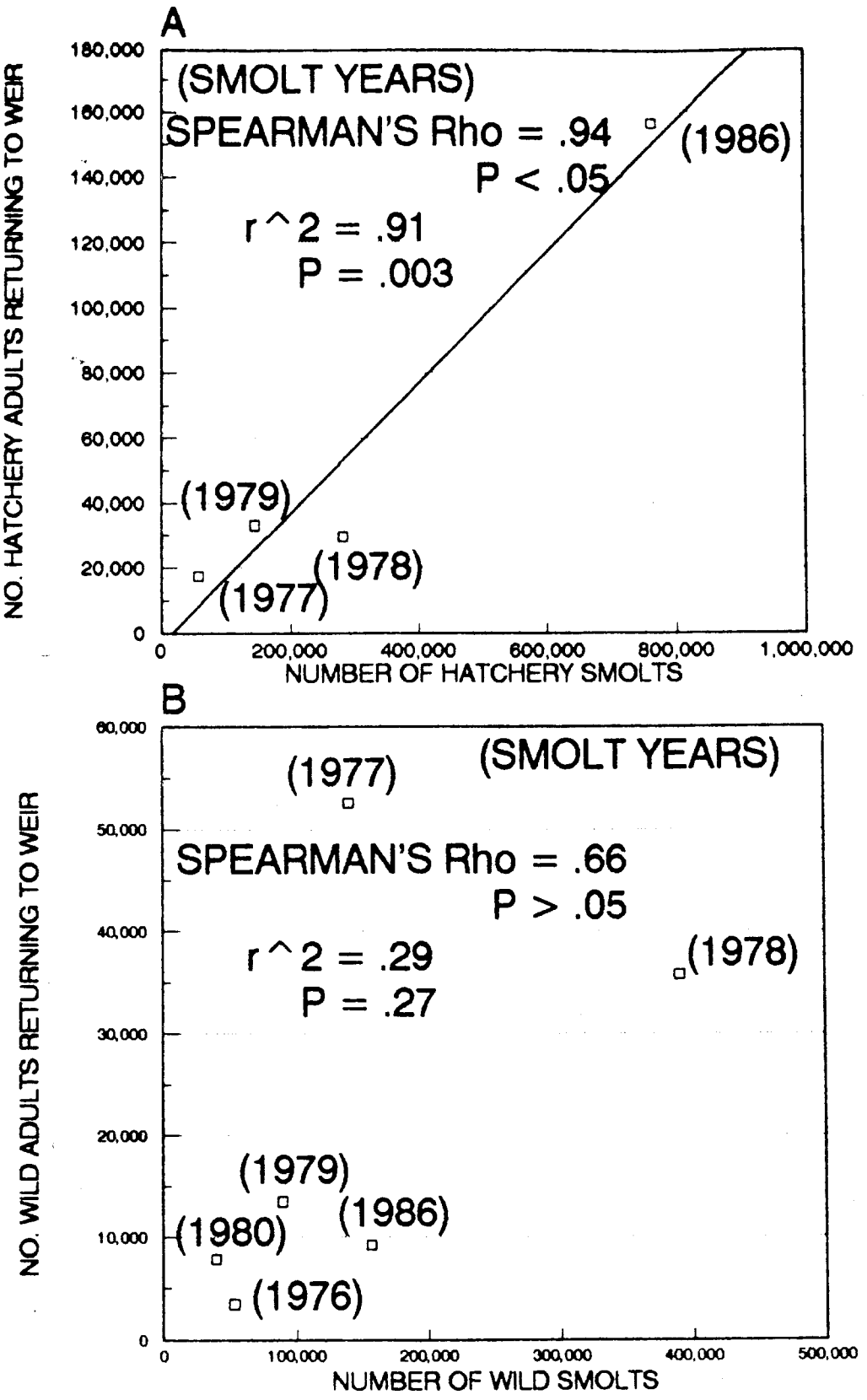

Figure 6. Relationships between hatchery (A) and wild (B) smolt production and respective returns of adult sockeye salmon to Big Lake.

(Figure 7). Thus, an increasing trend in sockeye salmon escapements into the Susitna River system during 1979-1989 was not evident, indicating that the increased sockeye salmon escapements into Big Lake resulted directly from the enhancement project.

DISCUSSION

Based on the significant relationship found between the number of hatchery fingerlings released and the number of hatchery smolts produced (Figure 4), it appears that in Big Lake, sockeye salmon production functions in a density-dependent fashion. However, this is contradicted by the non-significant relationship found between escapement into Big Lake and the number of wild smolts produced (Figure 5). In addition, the finding of no relationship between the total number of smolts produced and the weight of age-1 smolts (Figure 3) further indicates the density of rearing juvenile sockeye salmon in Big Lake did not affect the size of age-1 smolts. Thus, these findings promote the question whether hatchery fingerlings supplant wild fingerlings, or is one or more density-independent factors affecting production of wild smolts.

Moreover, the estimated fingerling-to-smolt survival for wild fish showed a decreasing trend, while that for hatchery fish increased (Table 3). The average survival of hatchery fingerlings to the smolt stage was 4.9%, and that of wild fingerlings was only 1.5%. In comparison, the survival of stocked sockeye salmon fingerlings to the smolt stage for two lakes located on the Kenai Peninsula; Hidden Lake, a highly-productive lake, and Tustumena Lake, which is very low in productivity, averaged 21.2% (Kyle et al. 1990a) and 17.2% (Kyle et al. 1990b), respectively. Thus, although increased numbers of fingerlings released into Big Lake resulted in greater numbers of hatchery smolts; the average smolt survival of the hatchery fingerlings was exceptionally low.

The potential smolt production of Big Lake based on the euphotic volume model (Koenings et al. 1989) is 1.2 million optimum-size sockeye salmon smolts; in addition, the potential smolt production based on zooplankton biomass (1985 data) indicates a

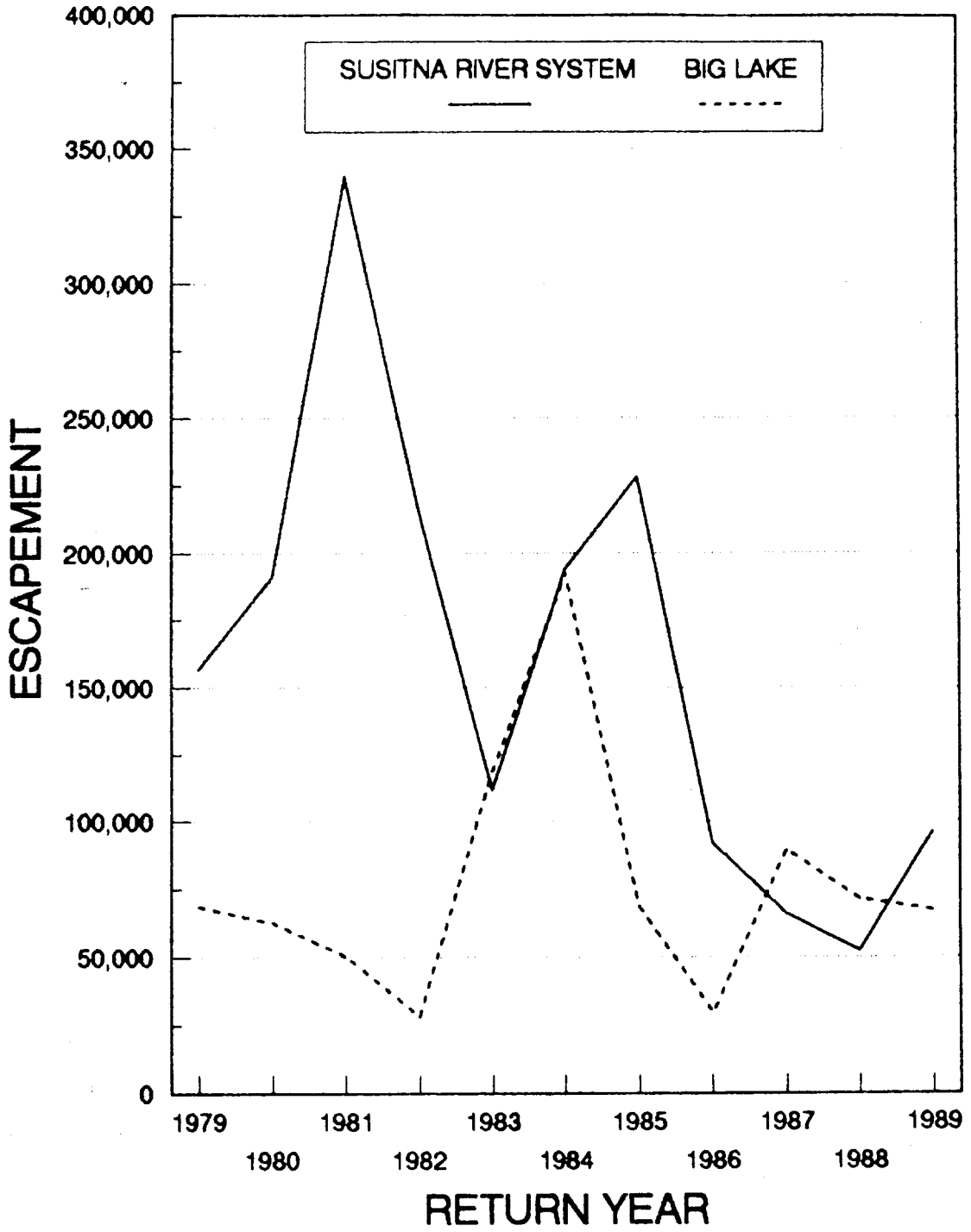

Figure 7. Comparison of sockeye salmon escapements into Big Lake and the Susitna River system for return years 1979-1989.

standing stock of zooplankton suitable to support production of 1.06 million optimum-size sockeye salmon smolts. The actual production of sockeye salmon smolts during 1976-1989 averaged 517,042 (Table 2) or approximately 50% of the potential production. In addition, the actual smolt production matched the potential production in only 2 of the 14 years during 1976-1989, and occurred when there was an above-average percentage contribution of hatchery-produced smolts.

Stock-separation techniques (Cross et al. 1979, 1980, 1981, 1982) indicate that the commercial harvest exploitation rate of Big Lake sockeye salmon during 1979-1982 averaged 54%. Using an estimated exploitation rate of 55% the estimated smolt-to-adult survival would average 36% (19.8% adult return to the weir [Table 5] divided by 0.55). However, in contrast to the fingerling-to-smolt survival for Big Lake, the estimated average survival (36%) of smolts to the adult stage seems high, as the smolt-to-adult survival for Hidden Lake sockeye salmon smolts, which are the same size as Big Lake smolts, averaged considerably less (28%). Thus, the stock-separation technique may overestimate the exploitation rate of Big Lake sockeye salmon in the mixed, commercial fisheries.

From the above, it is evident that further studies are needed to evaluate sockeye salmon production in Big Lake. In particular, it is apparent that factors other than the number of hatchery sockeye salmon fingerlings released, or the magnitude of natural recruitment in Big Lake, affect resulting production. Some of the more important factors to consider for continuing salmon enhancement in Big Lake include:

1) The effect of stocking coho salmon fingerlings (~ 1.5 million each year), and rainbow trout fingerlings and catchables in Big Lake, on the wild and hatchery sockeye salmon smolt production in regards to competition, predation, and causing observed sequences in populations of sockeye and coho;

2) Determination of the impact of residential and commercial development of lake-front lots in regards to water quality and trophic levels (i.e. altering nutrient ratios, phytoplankton compostions, and zooplankton compositions), to prevent trophic changes such as those that have occurred in nearby Finger Lake (Edmundson et al. 1989);

3) The effect of hatchery production on the natural stock of sockeye salmon in Big Lake, relative to the observed decrease in survival of wild smolts, and the contrasting relationships between hatchery and wild smolt production and the number of hatchery and wild adults returning to Big Lake (Figure 6) and;

4) Development of a management plan to define salmon production goals relative to economic and social interests, water quality assurance, fish habitat, and the future of fisheries enhancement in Big Lake.

RECOMMENDATIONS

1) Conduct a study or sampling to determine interaction between sockeye and coho salmon relative to competition, predation, and population dynamics to determine the effects on in-lake survival of sockeye salmon.

2) Conduct monthly limnological sampling during the ice-free months for two years to determine current general water quality, nutrient concentrations, and zooplankton compositions and biomass, relative to sockeye salmon production.

3) Monitor the in-lake population of rearing sockeye salmon juveniles through the summer by conducting hydroacoustic surveys.

4) Compile available data and information such as existing limnological data, water quality standards, phosphorus loading, residental and commercial development concerns, and hydrologic budget for lake water renewal

calculation, as a first step in developing a data base for use in developing a salmon managment plan for Big Lake, and for designing any remedial actions.

ACKNOWLEDGEMENTS

We acknowledge fishery biologist Carl Kalb and fishery technicians Braun Kopsack and Lee Cheney of ADFG for collection of field data. We also recognize the support of staff from the Big Lake Hatchery for the production of sockeye salmon fingerlings, and ADF&G fishery technicians Barry Stratton, Frederic Kraus, and Ed Snyder for field and logistical support.

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